

Blois07/EDS07**Vector meson electroproduction within GPD approach***S.V. Goloskokov*Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research,
Dubna 141980, Moscow region, Russia**Abstract**

We analyze electroproduction of light vector meson at small Bjorken x within the generalized parton distribution (GPD) approach. Calculation is based on the modified perturbative approach, where the quark transverse degrees of freedom in the hard subprocess are considered. Our results on the cross section are in fair agreement with experiment from HERMES to HERA energies.

1 Introduction

In this report, we investigate vector mesons electroproduction at small Bjorken x on the basis of the GPD approach [1, 2]. At large Q^2 the leading order amplitude with longitudinal photon and vector meson polarization (LL amplitude) dominates and factorizes [3] into a hard meson lepto-production off partons and GPDs, Fig.1. Other transition amplitudes are suppressed by powers

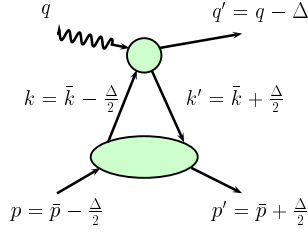


Fig. 1: The handbag diagram for the meson electroproduction off proton.

of $1/Q$ and obey singularities [4] in the collinear approximation. This leads to the problems with factorization of these amplitudes.

In this report, we analyse LL amplitude of vector meson electroproduction at large Q^2 . In contrast to [1], where the gluon predominant region $x \leq 0.01$ was considered, we extend here our analysis to $x \leq 0.2$ [2]. This range covers the energy region from HERMES to HERA energies. Our model is based on the modified perturbative approach (MPA) [5] which includes the quark transverse degrees of freedom accompanied by Sudakov suppressions. The transverse quark momentum regularizes the end-point region of the amplitudes. The $x \sim 0.2$ range study requires inclusion of the sea and valence quark GPDs in our analysis. It is shown, that in our model we obtain a fair description of HERMES, H1 and ZEUS data [6–8] for electroproduced ρ and ϕ mesons at small x [2].

2 Leptoproduction of Vector Mesons in the GPD approach

The parton contribution to the photoproduction amplitudes $\gamma^* p \rightarrow V p$ with positive proton helicity reads as a convolution of the hard subprocess amplitude \mathcal{H}^V and a large distance unpolarized H^i and polarized \tilde{H}^i parton GPDs :

$$\mathcal{M}_{\mu'+, \mu+}^V = \frac{e}{2} C^V \sum_{\lambda} \int d\bar{x} \mathcal{H}_{\mu'\lambda, \mu\lambda}^{Vi} H^i(\bar{x}, \xi, t), \quad (1)$$

where i denotes the gluon and quark contribution, μ (μ') is the helicity of the photon (meson), \bar{x} is the momentum fraction of the parton with helicity λ , and the skewness ξ is related to Bjorken- x by $\xi \simeq x/2$. The flavor factors are $C_\rho = 1/\sqrt{2}$ and $C_\phi = -1/3$. The polarized GPDs \tilde{H}^i at small x are much smaller than the unpolarized GPDs H^i and they are unimportant in the analysis of the cross section.

The subprocess amplitude \mathcal{H}^V is represented as the contraction of the hard part F which is calculated perturbatively and the non-perturbative meson wave function ϕ_V which depends on the transverse quark momenta k_\perp in the vector meson

$$\mathcal{H}_{\mu'\lambda, \mu\lambda}^V = \frac{2\pi\alpha_s(\mu_R)}{\sqrt{2N_c}} \int_0^1 d\tau \int \frac{d^2\mathbf{k}_\perp}{16\pi^3} \phi_V(\tau, k_\perp^2) F_{\mu'\mu}^\pm. \quad (2)$$

The wave function is chosen in the simple Gaussian form

$$\phi_V(\mathbf{k}_\perp, \tau) = 8\pi^2 \sqrt{2N_c} f_V a_V^2 \exp \left[-a_V^2 \frac{\mathbf{k}_\perp^2}{\tau\bar{\tau}} \right], \quad (3)$$

which leads after integration over k_\perp to the asymptotic wave function. Here $\bar{\tau} = 1 - \tau$, f_V is the decay coupling constant and the a_V parameter determines the value of average transverse momentum of the quark.

In calculation of the subprocess within the MPA [5] we keep the k_\perp^2 terms in the denominators of the hard amplitudes. The gluonic corrections in hard subprocess are treated in the form of the Sudakov factors which additionally suppress the end-point integration regions.

The GPD is a complicated function which depends on three variables. We use the double distribution form [9]

$$H_i(\bar{x}, \xi, t) = \int_{-1}^1 d\beta \int_{-1+|\beta|}^{1-|\beta|} d\alpha \delta(\beta + \xi\alpha - \bar{x}) f_i(\beta, \alpha, t), \quad (4)$$

with the distribution function

$$f_i(\beta, \alpha, t) = h_i(\beta, t) \frac{\Gamma(2n_i + 2)}{2^{2n_i+1} \Gamma^2(n_i + 1)} \frac{[(1 - |\beta|)^2 - \alpha^2]^{n_i}}{(1 - |\beta|)^{2n_i+1}}. \quad (5)$$

Here

$$\begin{aligned} h_g(\beta, 0) &= |\beta| g(|\beta|) & n_g &= 2 \\ h_{sea}^q(\beta, 0) &= q_{sea}(|\beta|) \text{sign}(\beta) & n_{sea} &= 2 \\ h_{val}^q(\beta, 0) &= q_{val}(\beta) \Theta(\beta) & n_{val} &= 1, \end{aligned} \quad (6)$$

where g and q are ordinary gluon and quark PDFs.

For the parton distribution the simple Regge ansatz is used

$$h_i(\beta, t) = e^{b_0 t} \beta^{-(\delta_i(Q^2) + \alpha' t)} (1 - \beta)^{2n_i + 1} \sum_{j=0}^3 c_i^j \beta^{j/2}. \quad (7)$$

The parameter $\delta_i(Q^2)$ is connected with the corresponding Regge trajectory. For example, for gluon we have

$$\delta_g(Q^2) = \alpha_P(0) - 1 = 0.1 + 0.06 \ln(Q^2/Q_0^2), \quad Q_0^2 = 4\text{GeV}^2, \quad (8)$$

which determines the behavior of the gluon distribution at low x and the energy dependence of the cross section at high energies. The parameter α' in (7) is a slope of the Regge trajectory $\alpha_i(t) = \alpha_i(0) + \alpha'_i t$. The other parameters in (7) are taken from comparison with the CTEQ6M parameterization [10].

The valence quark sea differs from the strange sea. The simple model is used

$$H_{sea}^u = H_{sea}^d = \kappa_s H_{sea}^s, \quad (9)$$

which is in correspondence with the CTEQ6 results. The flavor symmetry breaking factor is chosen in the form

$$\kappa_s = 1 + 0.68/(1 + 0.52 \ln(Q^2/Q_0^2)) \quad (10)$$

which fits well CTEQ6M PDFs.

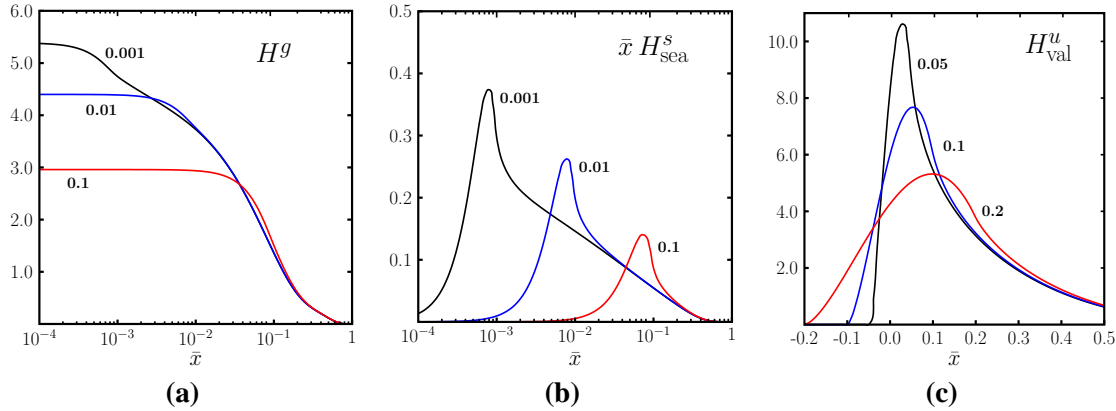


Fig. 2: GPDs (a) H^g , (b) $\bar{x} H^s_{sea}$, (c) H^u_{val} via x for some values of skewness. GPDs are shown at $t = 0$ and scale $Q^2 = 4\text{GeV}^2$

The model results for gluon and quark GPDs for different values of skewness are shown in Fig. 2.

3 Longitudinal cross section

Now we have all ingredients to calculate cross sections. Estimations for the vector meson production are obtained using $f_{\rho L} = 0.209 \text{ GeV}$, $a_{\rho L} = 0.75 \text{ GeV}^{-1}$; $f_{\phi L} = 0.221 \text{ GeV}$; $a_{\phi L} = 0.7 \text{ GeV}^{-1}$. The value of the diffractive peak slope can be found in [2]. The longitudinal cross section for the ρ and ϕ production integrated over t is shown in Fig. 3 at HERA energies. In this energy range the valence quark effects are unimportant. In Fig. 3a, the cross section of ρ production is shown together with the individual contributions to the cross section: gluon contribution, the gluon-sea-quark interference, and quark contribution. It can be seen that a typical contribution of the interference to σ_L does not exceed 50% with respect to the gluon one. Thus, the gluon term really gives the predominant contribution to the cross section [11] and we find good agreement of our results with the H1 and ZEUS experiments [7, 8] at HERA.

The model results for the ϕ production cross section shown in Fig. 3b are consistent with the H1 and ZEUS data [7, 8]. In ϕ production the gluon-sea quark interference contribution to the cross section does not exceed 25%. Note that the uncertainties in the GPDs provide errors in the cross section about 25 – 35% which are shown in Fig. 3b for ϕ production. The ρ production cross section in Fig. 3a has the similar uncertainties. They are of the same order of magnitude as the gluon-sea interference. The leading twist results which do not consider effects of transverse quark motion, are presented in Fig. 3b too. One can see that the k_{\perp}^2/Q^2 corrections in the hard amplitude denominators are extremely important at low Q^2 . They decrease the cross section by a factor of about 10 at $Q^2 \sim 3 \text{ GeV}^2$. The role of these corrections at $Q^2 \sim 40 \text{ GeV}^2$ is not so essential-about 40%.

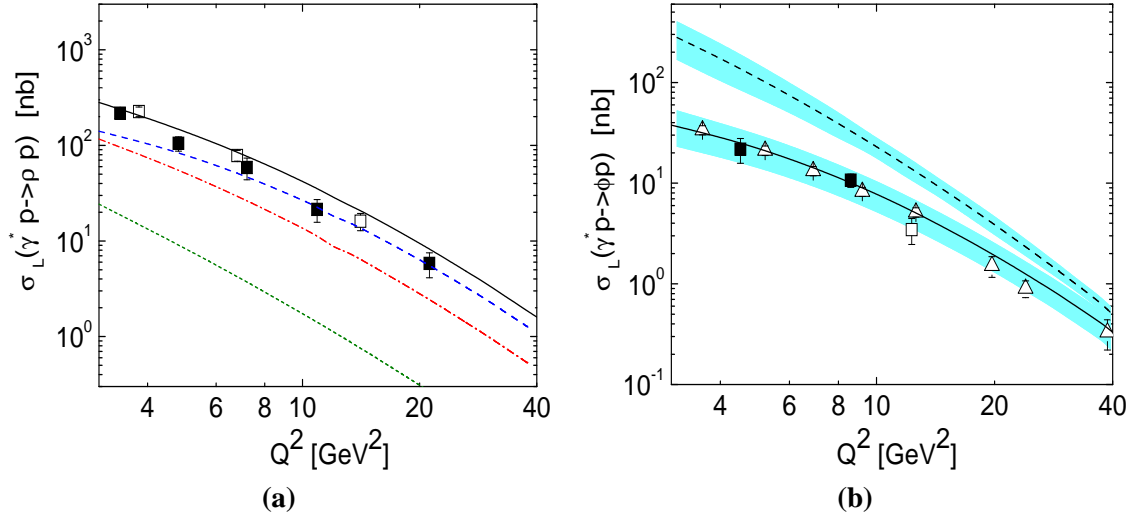


Fig. 3: **(a)** Longitudinal cross sections of ρ production at $W = 75 \text{ GeV}$. Full line cross section, dashed- gluon contribution, dashed-dot - gluon-sea interference, dotted line -sea contribution. **(b)** Full line- longitudinal cross sections of ϕ production at $W = 75 \text{ GeV}$ with error band from CTEQ PDF uncertainties. Dashed line -leading twist results. Data are from H1 and ZEUS.

Let us discuss the energy dependence of the cross section. At small x where only gluon

and sea contribute they behave as

$$\sigma_L \propto W^{4\delta(Q^2)}, \quad (11)$$

where the power δ is determined in (8). At larger x the valence quark contribution should play an important role. In Fig. 4 a, we show our results for the ρ - production cross section at $Q^2 = 4\text{GeV}^2$ in a wide energy range. Together with the gluon contribution, the gluon + sea and interference of valence quark with gluon + sea plus valence quark contribution to the cross section are shown. It can be seen that for energies above $W \geq 10\text{GeV}$ the gluon and sea effects well reproduce the cross section. At HERMES energies $W \sim 5\text{GeV}$ the valence quarks con-

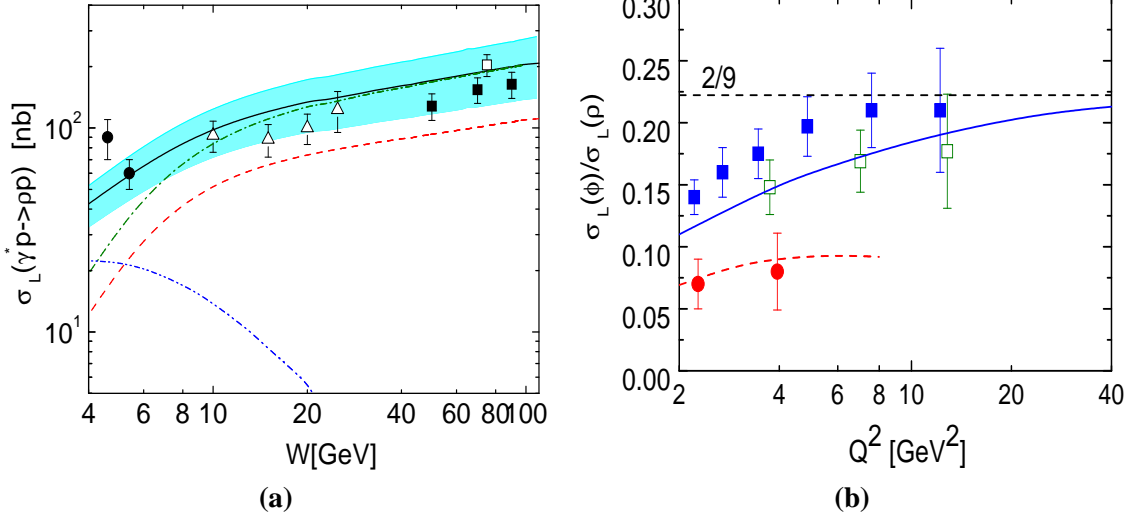


Fig. 4: **(a)** Longitudinal cross sections of ρ production at $Q^2 = 4\text{GeV}^2$ as a function of W . Full line cross section, dashed- gluon contribution, dashed-dot - gluon+sea, dashed dot dotted- (gluon+sea)-valence interference plus valence contribution. **(b)** The ratio of ϕ/ρ cross sections via Q^2 . Full line- $W = 75\text{GeV}$, dashed line - $W = 5\text{GeV}$. Data are from H1 and ZEUS and HERMES.

tribution is important. For ρ production the interference of valence quarks with gluons and sea contribution give of about 40% contribution to the cross section at $W \sim 5\text{GeV}$. At COMPASS energies $W \sim 10\text{GeV}$ the valence quarks give only about 10% contribution to the cross section. Thus, COMPASS physics is very close to asymptotic HERA energies.

The ratio of the ϕ/ρ cross sections at HERA energies $W = 75\text{GeV}$ is shown in Fig. 4.b. It is obvious that if the valence quark sea does not contribute (or sea is symmetric), this ratio is determined by the flavor factors in (1) and should be equal to $\sigma(\phi)/\sigma(\rho) = 2/9$. The HERA data show a strong deviation of this ratio from $2/9$ value. In our model, this violation at HERA energies and low Q^2 finds a natural explanation by the flavor symmetry breaking factor (10) effect. At high Q^2 the κ_s factor goes to 1 and the ratio of the cross section is close to the $\sigma(\phi)/\sigma(\rho) = 2/9$ limit. Thus, we can conclude that the Q^2 dependence of the $\sigma(\phi)/\sigma(\rho)$ ratio is completely determined by the flavor symmetry breaking factor κ_s . It cannot be explained if one does not consider the quark sea contribution. At HERMES energies the valence quarks contribution in ρ production gives an additional suppression the of $\sigma(\phi)/\sigma(\rho)$ ratio -see Fig. 4b.

4 Conclusion or Summary

We have analyzed electroproduction of light mesons at small Bjorken- x in the handbag model where the process amplitudes are factorized into the GPDs and a partonic subprocess. The subprocess was calculated [2] within the modified perturbative approach where the transverse momenta of the quark and antiquark as well as Sudakov corrections were taken into account. These effects suppress the contributions from the end-point regions where one of the partons entering into the meson wave function becomes soft and factorization breaks down in the collinear approximation. It is found that the GPD approach gives a fine description of the longitudinal cross section for light meson production. The power corrections $\sim k_{\perp}^2/Q^2$ in propagators of the hard amplitude play an extremely important role at low Q^2 . Inclusion of these corrections gives a possibility to describe experimental data properly.

The gluonic contribution plays an essential role for all energies $W > 5\text{GeV}$ in vector meson electroproduction. The gluon-sea interference is about 30(50)% for ϕ (ρ) production. Valence quarks contribute only for $W < 10\text{GeV}$. For the ρ production at HERMES energies $W \sim 5\text{GeV}$, valence quarks give about 40% effect in the cross section. At COMPASS $W \sim 10\text{GeV}$ their contribution is about 10% only. The flavor symmetry breaking of the sea naturally explain the deviation of the $\sigma(\phi)/\sigma(\rho)$ ratio from the asymptotic limit equal to 2/9 at HERA energies at low Q^2 .

Thus, we can conclude that in different energy ranges, information about quark and gluon GPDs can be extracted from the cross section of the vector meson electroproduction. This reaction at small x and large Q^2 is an excellent tool to study the gluon and quark GPDs.

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